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# Commuting, Spatial Search and Labour Market Bargaining

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# **Commuting, spatial search and labour market bargaining: an equilibrium model**

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## Commuting, spatial search and labour market bargaining: an equilibrium model

*Abstract: We develop an equilibrium job search model in which employees incur endogenous commuting costs. This model leads to the following conclusions:*

- 1. Firms partially compensate workers for the incurred commuting costs.*
- 2. When workers have more bargaining power, they will receive less compensation for the incurred commuting costs.*
- 3. The average commuting costs are an increasing function of the productivity level of the workers, but a decreasing function of the unemployment benefit level.*
- 4. Given balanced growth, the average commuting costs are proportional to the average wage in the long run.*
- 5. Given balanced growth, the average commuting time is constant in the long run, but the average commuting distance and speed are increasing over time.*

### **1. Introduction**

One of the central themes in the theory of commuting behaviour is that when housing and labour markets are perfect, wages and prices for house services will compensate for commuting costs (see Alonso, 1964; Madden, 1985; Ihlanfeldt, 1992; Zax, 1991).

Although empirical studies have demonstrated that workers indeed receive compensation for commuting expenses in both the housing and the labour market, the general conclusion is that this compensation tends to be only partial (Small, 1992; Ihlanfeldt, 1992; but see Zax, 1991). This suggests the occurrence of market imperfections such as discrimination (see Holzer, 1994), residential moving costs or incomplete information

(see van Ommeren et al., 2000). Empirical studies such as Zax (1991) or Ihlanfeldt (1992) also demonstrate that compensation for commuting expenses varies widely among different types of workers (males versus females, whites versus blacks) which "suggests that labour market power may help determine the extent to which workers can shift the burden of commuting expenses onto their employers " (Zax, 1991, page 205). The current paper aims to address this issue by developing a commuting model which explicitly takes labour market imperfections and bargaining between workers and employers into account.

More generally, the current paper can be interpreted as an attempt to understand commuting behaviour from a job search perspective. Job search theory is currently the main theoretical and empirical framework to analyse labour markets, building on the work of Stigler (1961, 1962). Search theory allows for market imperfections (lack of information, moving costs), and therefore avoids the problems associated with the standard urban economics model which assumes that markets are perfect (see Anas, 1982; Hamilton, 1982, 1989). Although the number of studies on commuting behaviour which explicitly make use of search theory is steadily increasing (see for example, Sugden, 1980; Simpson, 1980; van den Berg and Gorter, 1997; Rouwendal and Rietveld, 1994; Holzer, 1994; van Ommeren et al., 1999, 2000), these studies have been based on partial search models (an exception is Rouwendal, 1998). In contrast, the current study makes use of an equilibrium search model, also referred to as a job matching model (so search behaviour of job seekers and employers are both explicitly modelled and

commuting costs, wages, number of unemployed and number of vacancies are endogenously determined).

In this paper, we focus on the determinants and consequences of workers' commuting costs extending an equilibrium job search model often associated with the work of Pissarides (see Pissarides, 1990, 2000). One of the essential assumptions of this model is that workers and employers search for each other, and when they meet, they bargain about wage levels and decide whether or not to form a match. Based on this model, we are able to answer questions such as: how do labour market variables such as labour market tightness, productivity levels and unemployment benefits affect commuting costs? What determines the ratio of commuting costs to wages? To what extent are employees compensated for the incurred commuting costs? To most of these questions, the model generates unambiguous answers. Average commuting costs can be demonstrated to be an increasing function of the productivity level of workers (which may explain why empirical studies usually find that educational achievement has a positive effect on commuting distance (see, Rouwendal and Rietveld, 1994). Firms partially compensate workers for the incurred commuting costs.

In the model, the productivity level plays an important role as it determines the average commuting costs and wage level. The 20th-century labour market has been characterised by historically high levels of productivity growth, whereas the unemployment rate has remained roughly constant. We proceed therefore by making assumptions which guarantee that the unemployment rate does not depend on productivity level. Given this

balanced growth characterisation of the long run, the model implies that the ratio of the average commuting costs to the average wage must be constant in the long run. In order to derive a result which can be more easily tested, we proceed by making an assumption on the relationship between monetary commuting costs and travel speed. Given the assumption that the monetary costs are proportional to the travel speed, the model implies that the average commuting time is independent of the productivity level, and therefore constant in the long run (for a discussion of the empirical regularity of constant travelling time, and an extensive list of references see Golob et al., 1981).

As has been demonstrated elsewhere (Zax, 1991, 1994, Van Ommeren et al., 1998), workers' commuting behaviour depends on the spatial configuration of firms. Most studies take the spatial configuration of firms as given, and focus on one of the following extremes. At one extreme, it is presumed that firms are located at the same location in the Central Business District: the monocentric model. At the other extreme, it is presumed that there exists a continuum of firms uniformly distributed over space - the dispersed employment model. The monocentric model focuses on the optimal residential location of workers, and how house prices depend on the distance to the Central Business District. In contrast, in the dispersed employment model, house prices do not vary over space, and are therefore ignored, but it allows for a more realistic characterisation of the labour market (Seater, 1979, van Ommeren et al., 1998).<sup>1</sup> In the current paper, we will analyse

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<sup>1</sup> The appropriateness of the assumptions, and therefore the usefulness of the model, depends on the spatial configuration of jobs. It is useful to distinguish between non-overlapping urban areas, dominant in the United States, and overlapping urban areas, like the Netherlands, Belgium, or the Ruhr area in Germany. A priori, it is expected that the dispersed employment model is more



commuting behaviour using a dispersed employment model.

The outline of the current paper is as follows: in section 2, we introduce the job matching model. In section 3, we derive properties of commuting behaviour in the short and long run. In section 4, we focus on commuting time and endogenous travel speed. Section 5 concludes.

## **2. The Model**

### **2.1 The job matching model**

We presume a continuum of identical firms and residences, which are uniformly distributed over a two-dimensional space. The economy is closed.<sup>2</sup> Each residence is inhabited by one identical individual, who is either unemployed or employed. The unemployed search for jobs, the employed do not search (for an equilibrium model which includes on-the-job search, see Mortensen, 1994). The employed incur commuting costs  $t$ , where  $t$  includes both monetary and travel time costs. The unemployed search sequentially throughout geographical space, facing a uniform distribution of commuting costs. The commuting costs become known at the moment the unemployed job seeker and firm contact each other. A firm consists of only one job, which is either filled or unfilled. In order to fill a job, firms post a vacancy.

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appropriate to explain commuting behaviour in overlapping urban areas, whereas the monocentric model is more appropriate to explain behaviour in non-overlapping urban areas.

<sup>2</sup> The analogy is a long, narrow economy – effectively one-dimensional – that stretches sufficiently far that we can disregard boundary conditions.

It is relevant here to distinguish between random search and spatial search technologies (Seater 1979; Maier, 1995; van Ommeren, 1998). Random search implies that jobseekers search randomly throughout space, whereas spatial search implies that the jobseekers follow a certain spatial pattern. The assumption that all firms and individuals are identical implies that jobseekers prefer to contact the nearest firm, since a match with the nearest firm guarantees the lowest commuting costs. Given the assumption of sequential search, a plausible assumption is that jobseekers search randomly within an area in which a contact is expected to generate a job match. So, we will presume that jobseekers will not search in locations where there is a zero probability of generating a job match.

Suppose there are  $L$  identical individuals in the labour force. We let  $u$  denote the unemployment rate and let  $v$  denote the vacancy rate, defined as number of vacant jobs as a fraction of the labour force  $L$ . We assume the existence of a matching function  $n(uL, vL, T)$  that gives the number of contacts between unemployed and firms as a function of the number of unemployed  $uL$  looking for jobs, the number of firms looking for workers  $vL$  and the maximum commuting costs  $T$ . We assume a separable structure:  $n(uL, vL, T) = G(T) \cdot m(uL, vL)$ , where  $m(uL, vL)$  is the number of matches when  $T$  is infinite. We interpret  $G(T)$  as the share of matched combinations of unemployed and vacancies that are within the range  $T$ . The nonspatial component of the matching function  $m$  is assumed increasing in both its arguments, concave, and has constant returns to scale (empirical studies generally accept the assumption of an aggregate matching function

with constant returns to scale, see Petrongolo and Pissarides (2001)<sup>3</sup>. The spatial component of the matching function  $G$  is assumed to be non-decreasing in the maximum search range  $T$ . Because  $G(T)$  is interpreted as the share of matched combinations of unemployed and vacancies within the relevant search area, we have  $G(0) = 0$ ,  $G(T) \rightarrow 1$  for  $T \rightarrow \infty$ , and  $G'(T) > 0$ .

Given the constant returns to scale assumption, it follows that  $q$ , the nonspatial component of the rate at which jobs become contacted, can be written as:

$$q = \frac{m(uL, vL)}{vL} = m\left(\frac{u}{v}, 1\right) = m\left(\frac{1}{\theta}, 1\right),$$

where  $\theta = v/u$ . So,  $\theta$  is a measure of labour market tightness, defined as the ratio of the vacancy to the unemployment rate. Thus,  $q$  depends negatively on the ratio of the vacancy to the unemployment rate,  $\theta$ , and to emphasise this, we will write the job contact rate as  $Gq(\theta)$ . Similarly, it can be seen that the rate at which the unemployed become contacted equals  $\theta Gq(\theta)$ . Making use of the assumption that the nonspatial component of the matching function has constant returns to scale, it can be easily shown that  $\theta q(\theta)$ , the nonspatial component of the rate at which the unemployed are contacted, depends positively on  $\theta$ .

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<sup>3</sup> Most empirical studies have been based on aggregate data, but the number of studies which estimate spatial matching functions is steadily increasing (e.g., Burda and Profit, 1996; Coles and Smith, 1996; Burgess and Profit, 2001).

## 2.2 Employed and Unemployed

An individual receives a wage  $w$  when employed and incurs commuting costs  $t$ , and receives unemployment benefits  $z$  when unemployed. When employed, the commuting costs are exogenous to the worker (note however that workers and firms are able to influence the level of commuting costs by rejecting job matches, so commuting behaviour is endogenous in the model). In contrast, the wage is endogenous and the firm and unemployed bargain about the wage  $w$ . Given the value of the commuting costs  $t$ , firm and unemployed will bargain about the wage  $w$ , so  $w = w(t)$ . The worker will not keep the job forever. With probability  $\lambda$ , the worker will lose the job and become unemployed. The discount rate is denoted as  $r$ .

We denote by  $U$  and  $W(t)$  the expected (discounted) lifetime income of the unemployed and employed respectively. The lifetime income of the employed can be written as:

$$rW(t) = w(t) - t + \lambda(U - W(t)) \quad (1)$$

So, the lifetime income of the employed is equal to the sum of the net wage- the wage minus the commuting costs - and the expected change in lifetime income due to the probability of losing the job.

When firms and unemployed contact each other, they will only form a match when  $W(t) > U$ . We will demonstrate later on that this implies that there exists a maximum acceptable commuting cost  $T$ , called the reservation commuting costs, at which the

unemployed (and the firm) is indifferent between forming a match or continuing search.

It follows that only jobs incurring commuting costs less than  $T$  are accepted.

So, the unemployed become employed at rate  $G\theta q(\theta)$ . When unemployed, the job seeker does not know the value of the commuting costs  $t$ , but only the (cumulative) distribution of the commuting costs  $G(T)$ , implying that the lifetime utility of the unemployed can be written as:

$$rU = z + G\theta q(\theta)(W^e - U) \quad (2)$$

where  $W^e$  denotes the conditional expectation of the lifetime utility when employed, so  $W^e = E(W|t \leq T)$ . Interpretation of this Bellman equation is as follows: the unemployed receives benefits  $z$  and has a probability  $G\theta q(\theta)$  of becoming employed, expecting to receive an increase in lifetime income equal to  $W^e - U$ .

### 2.3 Job creation

The value of a vacancy,  $V$ , can be written as:

$$rV = -pc + Gq(\theta)(J^e - V) \quad (3)$$

where  $pc$  denotes the firms' hiring costs, which are presumed to be proportional to productivity and  $J^e$  denotes the conditional expectation of the job's net worth. Vacancies are filled at rate  $Gq(\theta)$ . The value of an occupied job with commuting costs, denoted as

$J(t)$ , can be written as:

$$rJ(t) = p - w(t) - \lambda J, \text{ or, similarly, } J(t) = \frac{p - w(t)}{r + \lambda}. \quad (4)$$

where  $p$  denotes the productivity level. In equilibrium, all profit opportunities from new jobs are exploited, driving rents from vacant jobs to zero, so  $V = 0$ . This equilibrium condition determines the supply of vacancies, implying that:

$$(r + \lambda)J^e = p - w^e = \frac{(r + \lambda)pc}{Gq(\theta)}, \quad (5)$$

where  $w^e$  denotes the expected wage level (so  $w^e = E(w|t < T)$ ). So, the net return of the job must be equal to the expected capitalised value of the firm's hiring cost. This condition is usually referred to as the job creation condition (Pissarides, 2000).

## 2.4 Wage determination

Recall that the commuting costs become known at the moment the unemployed job seeker and firm contact each other. The commuting costs are a drawing from a homogeneous distribution, and its value becomes known when firms and unemployed individuals meet. Given the commuting costs, the unemployed and firm bargain about the wage level, and may then accept or reject the match. In equilibrium, job matches yield a local-monopoly surplus. We assume that the total surplus, equal to the sum of the workers' surplus,  $W(t) - U$ , and the firms' surplus  $J(t) - V$ , is shared according to the Nash

solution to a bargaining problem, according to the following rule:

$$w(t) = \arg \max (W(t) - U)^\beta (J(t) - V)^{1-\beta} \quad (6)$$

where  $\beta$  may be interpreted as a measure of the workers' labour strength, other than the 'threat points'  $U$  and  $V$ , and can also be interpreted as the labour's share of the total surplus. We presume that  $0 < \beta < 1$ . The first-order equation satisfies:

$$W(t) - U = \frac{\beta}{1-\beta} (J(t) - V) \quad (7)$$

This equation implies that firms and workers agree on which job matches to accept, and which to reject.<sup>4</sup> The wage can then be written as (see appendix 1):

$$w(t) = (1 - \beta)(z + t) + \beta p + \beta p c \theta, \quad t \leq T \quad (8)$$

The above equation shows that the wage is increasing in the commuting costs  $t$ .<sup>5</sup> Further, and maybe surprisingly, it shows that the strength of the relationship between commuting costs and the wage depends negatively on the strength of the bargaining position of the

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<sup>4</sup> In equilibrium,  $V = 0$ , so when  $J$  is less than 0,  $W - U$  is also less than 0, therefore firms and job seekers agree not to form a match. In contrast, when  $J$  exceeds 0,  $W - U$  exceeds 0, so firms and job seekers both agree to form a match. When  $J = W - U = 0$ , firm and job seeker are both indifferent to forming a match or continuing searching.

<sup>5</sup> Further, the equation shows that the wage is increasing in the unemployment benefit level, the productivity level and the average hiring costs per unemployed.

unemployed, measured by  $1-\beta$ . In other words, when the unemployed receive a higher share of the surplus, they receive *less* compensation for the commuting cost. In the extreme situation that  $\beta$  approaches 0, the employed do not rec and will in the denotes in the long of eive any compensation for the commuting costs (but the full share of the surplus). In the other extreme situation that  $\beta$  approaches 1, workers receive full compensation for the commuting costs, but nothing from the surplus. Note that the interpretation of equation (8) is partial, since  $\theta$  is endogenously determined in the model (see later).

Maybe surprisingly, labour market tightness  $\theta$ , defined as the ratio of the vacancy rate to the unemployment rate, does *not* determine the extent to which workers can shift the burden of commuting expenses onto their employers. Note that workers claim a higher wage when  $\beta$  is higher ( $\beta$  is exogenous), and with higher wages firms create fewer jobs, increasing market tightness, creating a positive relationship between  $\beta$  and labour market tightness  $\theta$  (see Pissarides, 2000). Consequently, according to the current bargaining model, workers who belong to groups which are disadvantaged in the labour market (for example, females, blacks), who have lower  $\beta$ 's, and which therefore face high unemployment rates relative to vacancy rates (Holzer, 1994), will receive *more* compensation for the commuting costs (but will receive less from the surplus, hence they will receive lower wages). So, surprisingly, our model gives a theoretical foundation for the claim by Zax (1991) that labour market power determines the extent to which workers can shift the burden of commuting expenses onto their employers, but predicts the reverse relationship as suggested by the results of Zax (1991). Finally, note that the wage



equation does not depend on the distribution  $G$ . This implies that the extent to which workers can shift the burden of commuting expenses onto their employers does not depend on the distribution of firms and residences.

## 2.5 Reservation commuting costs

Job seekers and firms form a match when the commuting costs are less than the reservation commuting costs  $T$ . The existence of the reservation commuting costs can be easily shown.<sup>6</sup> The reservation commuting costs  $T$  can be derived by the condition that  $W - U$  is equal to 0, so  $J$  is equal to 0. The latter condition implies that:

$$p - w(T) = 0. \quad (9)$$

So the firm pays a wage equal to the productivity level, when the incurred commuting costs are equal to the reservation commuting costs. Using the wage equation (see (8)), the reservation commuting costs can be written as:

$$T = p - z - \frac{\beta}{1-\beta} pc\theta \quad (10)$$

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<sup>6</sup> The net wage, defined as the wage minus the commuting costs, is decreasing in the commuting costs, since  $1-\beta < 1$ . This implies that the lifetime income  $W$  is a decreasing function of the commuting costs  $t$  which is a sufficient condition for the existence of the reservation commuting cost  $T$ .

so, the reservation commuting costs are equal to the difference between productivity level and the unemployment benefits minus a share of the average hiring costs per unemployed ( $pc\theta$  is equal to the hiring costs times the number of vacancies divided by the number of unemployed and can therefore be interpreted as the average hiring costs per unemployed).

## 2.6 Equilibrium

In the steady state, the proportion of individuals who enter unemployment,  $\lambda(1-u)$ , must be equal to the proportion who would leave unemployment,  $\theta q(\theta)G(T)$ . So, the unemployment rate can be written as

$$u = \frac{\lambda}{\lambda + \theta q(\theta)G(T)}. \quad (11)$$

The expected wage,  $w^e$ , can be written as:

$$w^e = (1 - \beta)(z + t^e) + \beta p + \beta pc\theta. \quad (12)$$

where  $t^e = E(t|t < T)$ . Combining the job creation condition (5) and the expected wage equation (12), we arrive at the following condition:

$$(1 - \beta)(p - z - t^e) - \frac{(r + \lambda)pc}{q(\theta)G(T)} = \beta pc\theta, \quad (13)$$

which states that the firms' share of the instantaneous surplus of the match minus the additional wage paid due to the bargaining power of the job seeker is equal to the expected hiring costs per unemployed. Equation (13) can be solved uniquely for  $\theta$ .<sup>7</sup> Given  $\theta$ , the reservation commuting cost  $T$  are determined (see (10)), and given  $\theta$  and  $T$ , the equilibrium unemployment rate  $u$  is determined (12). So, the full equilibrium has been defined.

### **3 Properties of commuting**

#### **3.1 The short run**

The level of productivity has two effects on the reservation commuting costs (see (10)). Firstly, there is a positive effect: a higher productivity level enables firms to recruit workers from further away (firms have to pay higher wages to compensate for workers' commuting costs) whilst still being able to generate a surplus. Secondly, there is a negative effect: the firms' hiring cost increase and therefore labour market tightness increases, which improves the bargaining position of the unemployed so the reservation commuting costs will fall. However, differentiation of equations (10) and (13) establishes that the overall effect of productivity on the reservation commuting costs is positive. Consequently, the reservation commuting costs are an increasing function of the productivity level.

Given the value of the reservation commuting costs, we are able to calculate the expected commuting costs. Recall that we have assumed that firms and residences are uniformly

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<sup>7</sup> The value of  $\theta$  can be shown to be independent of  $T$ , an envelope property implied by the

distributed over space. Given this distribution, the expected commuting costs, denoted as  $t^e$  can be written as follows (which follows from the assumption that firms and residences are uniformly distributed over two-dimensional space, see Appendix 2):

$$t^e = \frac{2}{3} T . \quad (14)$$

Consequently, the expected commuting costs are proportional to the reservation commuting costs<sup>8</sup>, and the properties derived above for the reservation commuting costs hold also for the expected commuting costs. As a result, the expected commuting costs are an increasing function of the productivity level<sup>9</sup>.

### 3.2 The long run

Equation (13) demonstrates that labour market tightness, measured by the variable  $\theta$ , is determined by the productivity level  $p$ . To be more precise, the equation implies that labour productivity increases labour market tightness. This property of the model is intuitive for a short run equilibrium, since higher labour productivity levels increase wage levels relative to unemployment benefit levels (and commuting costs) which increase the

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optimality of  $T$ .

<sup>8</sup> When firms and residences are uniformly distributed over one-dimensional space, the expected commuting costs are equal to  $1/2 T$ , and the expected commuting costs are also proportional to the reservation commuting costs.

<sup>9</sup> Since labour market tightness is procyclical, the model suggests that average commuting costs should be anticyclical over the business cycle. This theoretical result has some empirical foundation. For example, the study by Burgess and Profit (2001) suggests that in good times, the unemployed lower their search radius.

utility of employment relative to unemployment. As a result, unemployment falls relative to the number of vacancies. Nevertheless, it is not an attractive property of a long-run equilibrium as it may be inconsistent with balanced growth (Pissarides, 1987; Aghion and Howitt, 1994 ). Balanced growth implies that productivity increases do not reduce unemployment rates. In the long run, the empirical evidence seems to indicate that wages completely absorb productivity increases, and productivity increases do not decrease unemployment levels (see also Wilson, 1995) <sup>10</sup>. We will therefore investigate restrictions which may guarantee that labour market tightness is independent of productivity level  $p$ .

In the model above both productivity level  $p$  and the unemployment benefit level are exogenous. However, it is plausible to assume that the unemployment benefit  $z$  is proportional to the productivity level:

$$z = \eta p \tag{15}$$

The above assumption is usually justified in the balanced growth literature on the grounds that  $z$  is primarily unemployment insurance income, which is fixed in terms of the average wage rate (see, for example, Pissarides, 2000, p. 21). This implies that:

$$T = p - \eta p - \frac{\beta}{1-\beta} p c \theta \tag{16}$$

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<sup>10</sup> In particular, the second half of the 20th-century has been characterised by historically high levels of productivity and wage growth, in all but a few countries, but unemployment rates have remained roughly constant.

and making use of equations (10) and (12), and the relationship between reservation commuting costs and the expected commuting costs ( $T = 3/2t^e$ ), we obtain the following two equations for the expected wage and the expected commuting costs.

$$w^e = (1 - \beta)(\eta p + t^e) + \beta p + \beta p c \theta \quad (17)$$

and

$$t^e = (2/3)(p - \eta p - \frac{\beta}{1 - \beta} p c \theta) \quad (18)$$

If we substitute now the expected commuting costs equation into the expected wage equation, then it follows that the expected wage and the expected commuting costs are both proportional to the productivity level, implying that expected commuting costs are proportional to the expected wage, when labour market tightness does not depend on productivity. Using equations (11, 13, 15 and 17), it can be seen that labour market tightness and unemployment do not depend on the productivity level  $p$  only when  $G(T)$  is independent of  $T$ , so  $\partial G/\partial T = 0$ . Thus, balanced growth can only be obtained as a property of this model when distance friction in the matching process is unaffected by productivity changes ( $G(T) = \text{constant}$ ). An example might be an island economy where transport costs are so low that all jobs and workers are within the critical search range so that increases in the search range induced by productivity changes do not lead to a more efficient matching process. Another possible case for a constant distance friction is found

when productivity changes might be expected to lead to relocation of households further away from employment centres. In such an analysis also spatially differentiated housing prices would play a role. This relocation behaviour would imply an increase in the distance related matching frictions that would counterbalance the decrease in matching frictions owing to the longer search range. However, in the present model such relocation behaviour does not take place since we have assumed a uniform spatial distribution of jobs and houses. Another possible case is that increases in the area of search induces more job specialisation, which increases productivity without reducing unemployment levels. Finally, it is plausible that the value of being unemployed,  $z$ , is endogenously determined by the government aiming to keep the unemployment rate (roughly) constant. In this case, the value of being unemployed increases overtime, but the balanced growth assumption still holds.

#### **4. Commuting time and endogenous travel speed**

Recall that all job seekers are assumed to be identical, so the expected wage is equal to the average wage and the expected commuting costs are equal to the average commuting costs. Consequently, the balanced growth assumption implies that average commuting costs are proportional to the average wage in the long run, which can be tested in principle.

Although the relationship between average commuting costs and average wages is in principle testable, we realise that empirical investigations of this relationship may be difficult, since workers' commuting costs consist of two components - monetary commuting costs and travel time costs - and the measurement of these two components

over time is not straightforward. In order to generate a relationship which can be more easily tested, we will proceed by making an assumption on the relationship between monetary commuting costs and travel speed in the next section.

Above we have presumed that the commuting costs are determined by a drawing from a homogeneous distribution, ignoring the travel mode decision. Here we extend the model by assuming that the unemployed search through space and contact vacancies at a commuting distance  $d$ . So, the commuting distance  $d$  is determined by a drawing from a homogeneous distribution. The commuting costs are then determined by the travel mode conditional on the commuting distance  $d$ . The choice of the travel mode determines of course the travel speed.

It is useful to distinguish between monetary travel costs per one distance unit, denoted as  $\$m$ , and the time travel costs, which depend on the travel speed. The value of the time travel costs is determined in the labour market model. Under the condition that the employee has no preference between time spent commuting or time spent working and the condition that the employees can freely choose the number of working hours per day, the hourly time travel costs are equal to the wage rate. In some cases, these conditions are too restrictive. For example, employees may prefer commuting, when the commute involves walking or involves listening to the radio in the car. In other words, the hourly time travel costs may be less, or more, than the wage rate. We therefore assume that the hourly time travel costs are *proportional* to the wage rate with parameter  $\psi$ . Further, for



convenience, we normalise the number of working hours per day to 1 such that the wage is equal to the wage rate.

We denote the speed of travel with  $s$ , so  $d/s$  denotes the travel time, which implies that the hourly time travel costs can be written as  $\psi wd/s$ . We denote the monetary costs per distance with  $\$m$ . Total commuting costs  $t$  can then be written as:

$$t = \left(\frac{w}{s} + \$m\right)d \quad (19)$$

The monetary costs per distance,  $\$m$ , depend on the travel mode and therefore on the travel speed. Here it is assumed that the monetary costs per distance are proportional to (and increasing in) the speed  $s$ .<sup>11</sup> This implies that total commuting costs can be written as:

$$t = \left(\psi \frac{w}{s} + s \tau\right)d \quad \tau > 0, \psi > 0 \quad (20)$$

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<sup>11</sup> The standard way to study modal choice is to apply discrete choice methods. In the present context we model it as a continuous model for speed choice. Clearly, as one proceeds from one mode to the other (for example bike to bus) a discrete jump takes place in terms of both speed and costs. A listing of the various modes according to average speed and cost per km travelled confirms that the two features are indeed close to proportional (for example, Bouwman, 2000). Also, as one travels faster within a given transport mode (for example car) the monetary costs per km travelled will be higher.

Conditional on the commuting distance, the employee will choose the optimal speed by minimising the total costs  $t$ . The first-order condition implies then that:

$$\psi \frac{w}{s} = s \tau = \$m, \quad (21)$$

in other words, the optimal speed is chosen such that the time travel costs are equal to the monetary travel costs. This latter result has some empirical foundation.<sup>12</sup> So, it follows that  $s$  can be written as  $\sqrt{\psi w / \tau}$ . Consequently, the total travel costs can be written as:

$$t = 2\psi \frac{w}{s} d \quad (22)$$

So, the commuter chooses the travel speed such that the total travel costs are twice the time travel costs.

Recall that we have demonstrated (at the end of section 3.2) that in the long run the average commuting costs are proportional to the average wage, which guarantees a consistent equilibrium growth path. This has several important implications. The first implication is that the average commuting *time* is independent of the productivity level and therefore constant in the long run, whereas the average commuting distance and the

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<sup>12</sup> For example in the Netherlands the monetary value of a trip by car is about 12-15 Eurocents per km. The average value of time is about 8 Euro per hour (see HCG, 1990). Then with an average speed of 60 kms per hour the time costs are  $800/60=13.3$  Eurocents per km.

average speed are increasing in the productivity level. This result can be derived as follows: when the average travel costs are proportional to the average wage rate then it follows that average commuting time, denoted as  $E(d/s)$ , is insensitive to variations in the productivity level (see Appendix 3). Moreover, an increase in the productivity level implies higher wages and therefore higher time travel costs and thus higher monetary travel costs, see equation (21). Consequently, the average speed  $s$  increases. A constant average commuting time and an increasing travel speed implies an increase in the average commuting distance. Alternatively, when the balanced growth assumption does not hold (see section 3.2), average commuting time decreases over time, because the increase in travel speed dominates the increase in commuting distance.<sup>13</sup>

## 5. Conclusion

The model introduced in the current paper is an extension of a standard matching model, which aims to analyse equilibrium unemployment, using search theory (unemployed search for jobs; firms search for applicants). This matching model is essentially a macro economic model using micro economic behavioural assumptions on job search, recruitment and wage bargaining. We have extended this standard basic model by presuming that workers incur commuting costs. Jobseekers and firms determine the average commuting costs by rejecting matches which are not profitable (commuting costs of unprofitable matches are too high). The maximum commuting costs, the wage level, unemployment and vacancy rate are then endogenously determined.

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<sup>13</sup> In the short run, it is plausible that the travel speed remains constant, so the average commuting

Labour market imperfections (for example, search costs) and bargaining between workers and employers play an essential role in the model. In contrast to models that exclude (labour) market imperfections, but in line with most of the empirical literature, workers are only partially compensated for the incurred commuting costs. In line with the findings of Zax (1991), we demonstrate that labour market power determines the extent to which workers can shift the burden of commuting expenses onto their employers, but, maybe surprisingly, the model predicts that workers belonging to groups which have more labour market power will receive less compensation.

Commuting costs are endogenously determined in the current model, which enables us to derive the effect of a number of labour market variables on average commuting costs. The average commuting costs are an increasing function of the productivity level of the workers, but a decreasing function of the unemployment benefit level.

The concept of balanced growth has been introduced in the search-equilibrium literature by Pissarides (1990). Balanced growth in a labour market model implies that in the long run when productivity levels grow, the unemployment rate will remain constant. One of the implications of balanced growth is that the ratio of the average commuting costs to average wages remains constant. Given the assumption that the monetary costs are proportional to the travel speed, the average commuting time is independent of the productivity level, and consequently constant in the long run.

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time may increase as a result of a productivity increase.

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## Appendix 1: The Wage Equation

Equations (5) and (7) imply that:

$$W^e - U = \frac{\beta}{1-\beta} \frac{pc}{Gq(\theta)} \quad (23)$$

whereas equations (2) and (23) imply that:

$$rU = z + \theta \frac{\beta}{1-\beta} pc. \quad (24)$$

Further, equation (1) can be rewritten as:

$$W - U = \frac{w - t - rU}{r + \lambda}. \quad (25)$$

Making use of equations (7) and (4) and the 3 above mentioned equations reveals that:

$$\frac{w - t - rU}{r + \lambda} = \frac{w - t - z - \theta \frac{\beta}{1-\beta} cp}{r + \lambda} = \frac{\beta}{1-\beta} \frac{p - w}{r + \lambda}. \quad (26)$$

Reordering of the second part of the equation, gives us wage equation (8).

## Appendix 2: The Expected Commuting Costs

The assumption of homogeneous distribution of residences and vacancies, implies that the conditional cumulative distribution of commuting costs  $G(t|t < T)$  is equal to  $2t\pi/\pi T^2 = 2t/T^2$ . The conditional expected commuting costs are then  $2/3 T$ .

## Appendix 3: The Expected Commuting Time

Expected commuting time  $E(d/s)$  is equal to  $E(t/w)/2\psi$  (see equation (22)). Note that the wage  $w$  is a linear function of commuting costs  $t$ , so  $w = a + kt$ , where  $a$  is proportional to productivity level  $p$  and  $k$  is equal to  $1 - \beta$  (see (8) and (15)). Further, as noted in Appendix 2, the density of commuting costs equals  $2t/T^2$ . So,  $E(t/w)$  can be written as:

$$\frac{2}{T^2} \int_0^T \frac{t^2}{a + kt} dt = \frac{2}{aT^2} \int_0^T \frac{t^2}{1 + bt} dt = \frac{2}{ab^3T^2} (\log(1 + bT) - bT + \frac{1}{2}b^2T^2) \approx \frac{2T}{3a} \text{ where } b = k/a,$$

since  $\log(1 + bx) = bx - (bx)^2/2 + (bx)^3/3 - (bx)^4/4 + \dots$  for  $bx < 1$  using a Taylor series approximation. Note that  $T$  and parameter  $a$  are both proportional to productivity level  $p$ , so we may conclude that the (approximated) expected commuting time is independent of the productivity level. The approximation is especially good for lower values of  $bT$ . Reasonable values of  $b$  and  $T$  are 0.5 and 0.5 respectively (so the reservation commuting costs are 50 % of the wage and bargaining power is equal to 0.5, which is reasonable according to Pissarides, 2000). In this case, the approximation error of expected commuting time is about 0.36%

